1977ICRC....1..296O

COSMIC-RAY AGE AND A MEASUREMENT OF THE ABUNDANCE OF Be^{10} USING A MAGNETIC SPECTROMETER *

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ABSTRACT

The abundances of isotopes from Li to C have been measured using our superconducting magnetic spectrometer in a balloon-borne experiment flying at a residual atmosphere of about 6 g/cm^2. In particular, we report the measurement of the isotopes of beryllium from 1.5 to 3 GV/c (i.e. 200-600 MeV/nucleon for Be^{10}) with a mass resolution ranging from 0.25 to 0.4 amu and with high efficiency. The detection technique, which utilizes dE/dx measured in a 2.5 cm plastic scintillator versus rigidity measured in the spectrometer, is described in detail along with an accelerator calibration of the scintillator. Mean ages for cosmic rays can be inferred from these Be observations and calculated abundances using several propagation models.

I. INTRODUCTION

Radioactive isotopes have long been recognized as clocks which could measure the cosmic ray propagation time. Be^{10} is practical for such a measurement since it is the most abundant radioactive isotope and because its mean life of 2.2 (half life = 1.5) million years approaches the expected range of cosmic ray ages. In this paper we describe the construction and calibration of an instrument capable of separating the isotopes of Beryllium. Previous experiments (Preszler, et al., 1975; Garcia-Munoz, et al., 1975; and Hagen, et al., 1977) have separated Be^{10} within an energy range from 40 to 290 MeV/nucleon; the present experiment covers the energy range from 200 to 600 MeV/nucleon. At these higher energies, interpretation of the results is less subject to systematic uncertainties from solar modulation and energy dependence in the Be^{10} production cross sections. The apparatus separates isotopes by using a superconducting magnetic spectrometer to measure the rigidity of each event and a large plastic scintillator to measure the specific energy deposition.

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* This work supported by N.A.S.A. grant NGR-05-003-553, and by the Lawrence Berkeley Laboratory.

II. APPARATUS

A schematic of the apparatus is shown in Figure 1. The balloon-borne magnetic spectrometer is described in Smoot, et al. (1973). Four modifications have been made since then to convert the apparatus for Be^{10} measurement: (1) a scintillation counter called the "isotope counter" has been introduced between scintillation trigger counters S_3 and S_4, (2) the middle spark chamber SC-2 was replaced with a thin-foil unit, (3) the trigger counter S_2 was replaced by an anticoincidence counter hole to define the region of high magnetic field integral, and (4) the trigger requirements have been changed as described below. Changes (2) and (3) were made to minimize the material for multiple Coulomb scattering in the spectrometer. The superconducting magnet, cameras, and optics remain unchanged.

The 2.5 cm thick isotope counter scintillator was placed near the top of an aluminum box (16 x 51 x 81 cm) painted inside with white diffusive $BaSO_4$ paint. The reflectivity averaged over the box is 97%. The box is viewed by four 5-inch photomultipliers (RCA C70133) through air light pipes (15 cm long) constructed from aluminized plexiglas. The total collection and conversion efficiency is about 1%. The photomultipliers are in a region of inhomogeneous magnetic field that averages about 1 kilogauss. The severe shielding problem was solved with a combination of mu-metal and soft iron shields, and bucking coils around both the light pipes and the phototube necks. The coils typically have 100 to 200 ampere-turns. The weight of each phototube, lightpipe, and shielding assembly is about 25 kilograms. The anode signal of each tube is individually digitized with 1024 bits and recorded by bit lights on the film. In addition, the last dynode signals are passively added, inverted, and digitized. Table I gives a summary of specifications for the apparatus.

TABLE I: APPARATUS SPECIFICATIONS

Scintillators:	S1	1.3 x 89 x 69 cm	Pilot Y
	S2	56 x 33 cm (hole)	NE-110
	S3	0.9 x 76 x 46 cm	Pilot Y
	Isotope	2.5 x 76 x 46 cm	NE-110
	S4	1.3 x 86 x 61 cm	Pilot Y
	Magnet Anti	76 cm diameter	
Magnet:	1.64×10^5 ampere-turns, yielding 5 kG-m mean field integral		
Gondola Mat'l:	Above S1	$0.8 \ g/cm^2$	
	Within spectrometer	3.4×10^{-3} rad. len.	
	Total instrument	$8 \ g/cm^2$	

The thresholds for the trigger counter pulse heights are defined in terms of the most probable ionization of a relativistic Z=1 particle and are set using ground level muons. A threshold of 11 times Z=1 is used for S_1 and S_3 to eliminate the large flux of hydrogen and helium. A threshold of 1 times Z=1 is used for S_4 to guarantee full penetration of the isotope counter. A radio-commandable upper threshold on S_1 set at 75 times Z=1 excludes the oxygen and higher-Z nuclei. Figure 2 shows the region of dE/dx versus rigidity space that the trigger will accept.

III. RESOLUTION

The expected error on the final relative abundance of Be^{10} is a function of the total number of events observed and the mass resolution. The expected mass resolution $\delta(A/Z)$ is plotted as a function of rigidity in figure 3. In the interval from 1.5 GV/c (geomagnetic cutoff) to 3 GV/c, the resolution varies from 0.25 to 0.4 amu for Beryllium. At lower rigidities the resolution is dominated by the error in the rigidity measurement, but at higher rigidities variation in dE/dx is dominant.

Using a flux of 0.3 events per m^2ster sec in the region of good resolution between 1.5 and 3 GV/c, and our geometry factor of 0.08 m^2ster, we estimate a total of about 10^3 well-resolved Beryllium events will be recorded during a flight with 10 hours live time.

IV. ACCELERATOR CALIBRATIONS

The isotope counter was tested at the Berkeley Bevatron in beams of N^{14}(5.8 GV/c), C^{12}(2.9 GV/c), and He^4(3.5 GV/c). In addition, the response to ground level cosmic ray muons was measured, giving typically 300 photoelectrons for each Z=1 particle incident. For each of the beams, the peak and the full width at half maximum of the pulse area distribution were measured. The ratios of the peaks and the widths are consistent with the Simon-Landau theory, the known photoelectron statistics, and scintillation and electronic saturation.

During the Bevatron runs the counter was moved transverse to the beam to map the spatial uniformity. The peak of the pulse area distribution for each of the four tubes was recorded for each beam position, and was found to vary by as much as a factor of two. However, the linear sum of the four tubes with an optimized gain for each gave a signal which was quite uniform over the counter. The rms deviation about the mean of this signal was about 3%. A correction for this small non-uniformity can be made from the flight data usin the abundant relativistic carbon nuclei events. The residual non-uniformities will be less than one-half percent and thus will make a negligible contribution to the mass resolution.

V. PRELIMINARY RESULTS

At the time of submission (1 May, 1977), the instrument was ready for launch from Aberdeen, South Dakota. Hopefully, a successful flight will be achieved and, by the time of the conference, preliminary results will be available.

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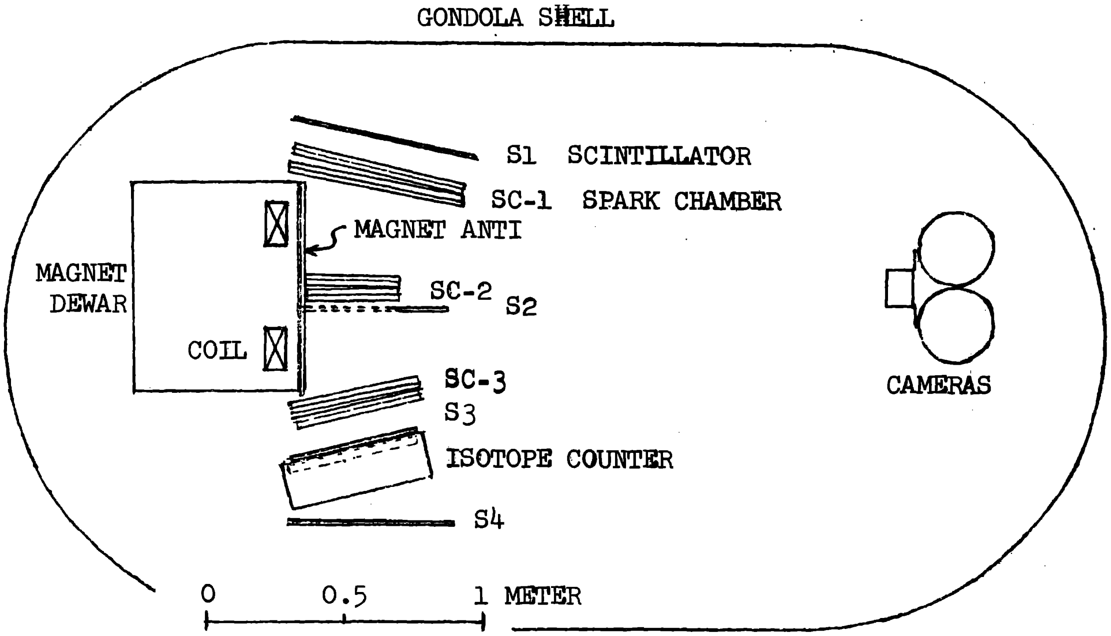

FIGURE 1. A schematic of the apparatus.

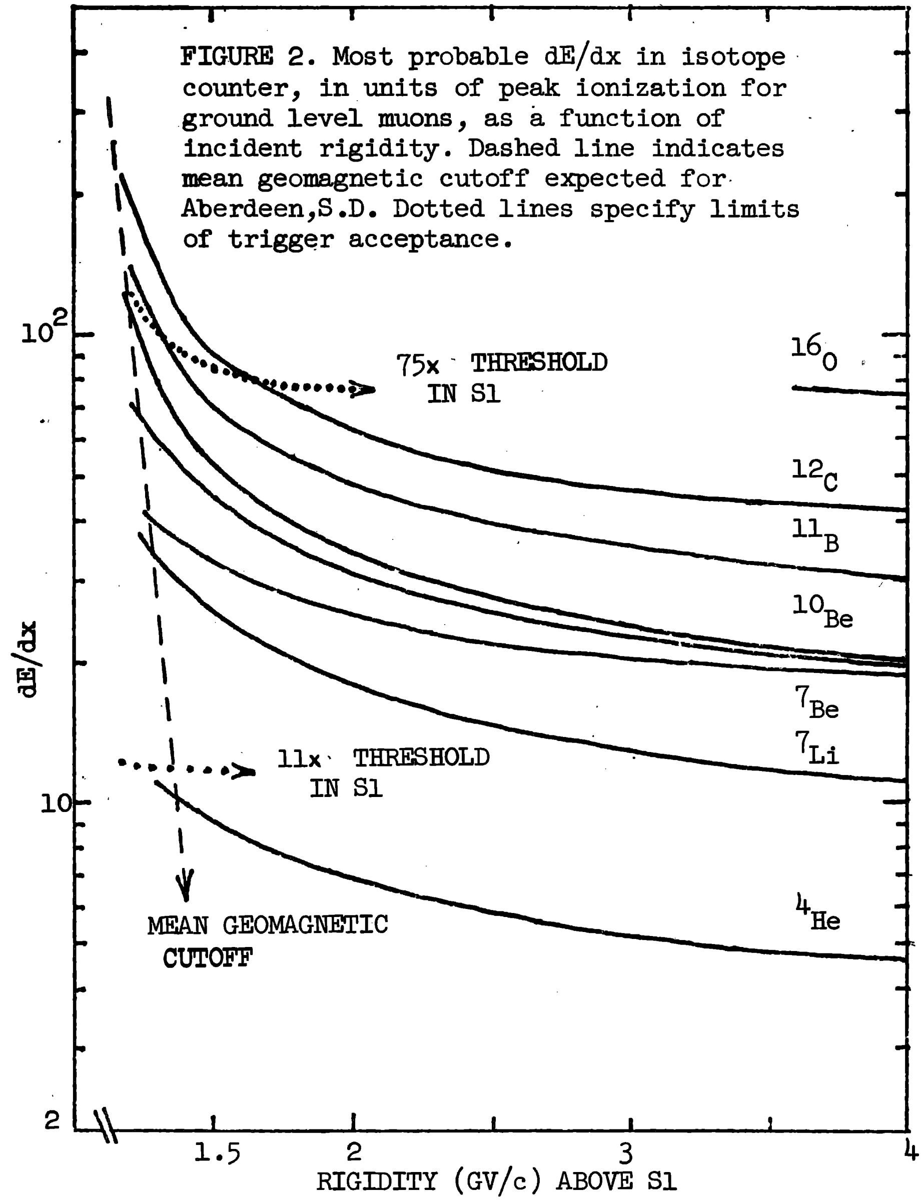

FIGURE 2. Most probable dE/dx in isotope counter, in units of peak ionization for ground level muons, as a function of incident rigidity. Dashed line indicates mean geomagnetic cutoff expected for Aberdeen, S.D. Dotted lines specify limits of trigger acceptance.

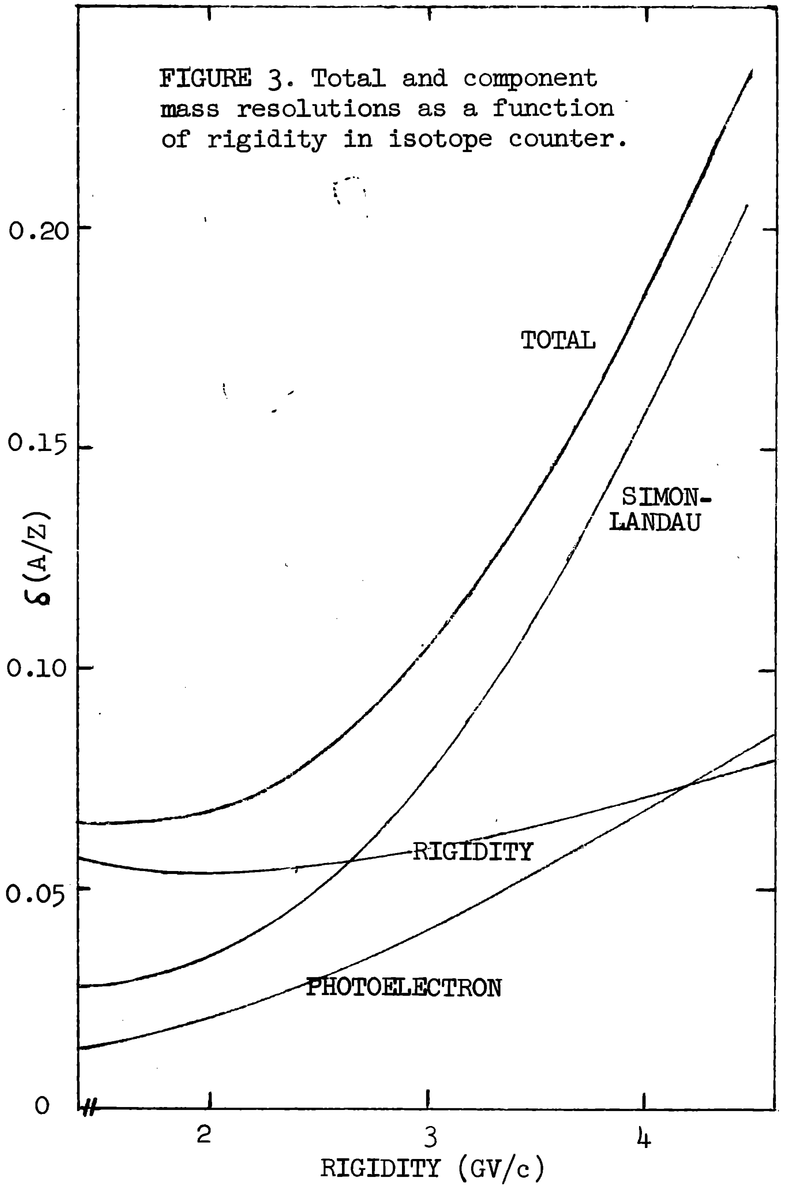

FIGURE 3. Total and component mass resolutions as a function of rigidity in isotope counter.